NEW DIFFRACTION RESULTS FROM THE TEVATRON

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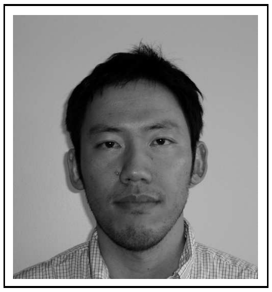

We present new results from studies on diffractive dijet production and exclusive production of dijet and diphoton obtained by the CDF Collaboration in proton-antiproton collisions at the Fermilab Tevatron.

1 Introduction

Diffractive events in $\bar{p}p$ collisions are characterized by the presence of a leading proton or antiproton which remains intact, and/or a rapidity gap, defined as a pseudorapidity[a] region devoid of particles. Diffractive events involving hard processes ("hard diffraction"), such as production of high E_T jets, have been studied to understand the QCD aspects of the exchanged object, the Pomeron (a color singlet entity with vacuum quantum numbers). One of the most important questions in hard diffractive processes is whether or not they obey QCD factorization, in other words, whether the Pomeron has a universal, process independent, parton distribution function (PDF). Results on diffractive deep inelastic scattering (DDIS) from the ep collider HERA show that QCD factorization holds in DDIS. However, single diffractive (SD) rates of W-boson, dijet, b-quark and J/ψ productions relative to non-diffractive (ND) ones measured in Run I at CDF [1] are about an order of magnitude lower than expectations from PDFs determined at HERA, indicating a severe breakdown of QCD factorization in hard diffraction between Tevatron and HERA. The suppression relative to predictions based on DDIS PDFs has been further studied by measuring "diffractive structure function" F_{jj}^D using diffractive dijet data in CDF [2]. The F_{jj}^D was measured by looking at the ratio R_{ND}^{SD} of SD to ND dijet event rates as a function of Bjorken-x variable (x_{Bj}) and multiplying the ratio by the known ND proton structure function.

[a] The pseudorapidity η of a particle is defined as $\eta \equiv -\ln(\tan\theta/2)$, where θ is the polar angle of the particle with respect to the proton beam direction.

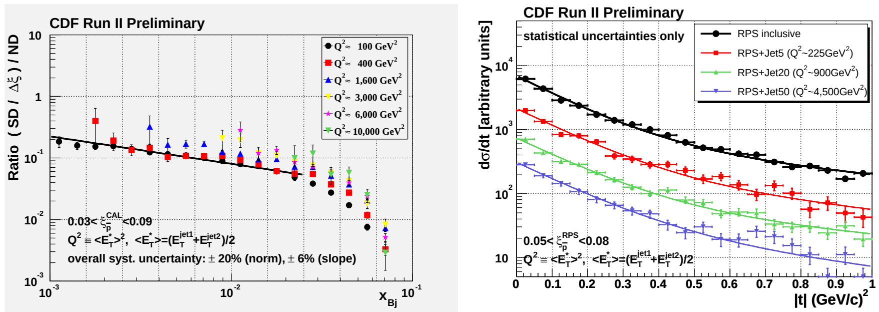

Figure 1: *Left*: Ratio of SD to ND dijet rates as function of x_{Bj} of the parton in the antiproton for different Q^2 ranges. *Right*: t distributions (with arbitrary normalization) in diffractive dijet events with different Q^2 values.

Measuring the ratio R^{SD}_{ND} thus provides information regarding the behavior of F^D_{jj} relative to the ND proton PDF.

Another area of great interest is exclusive production of dijets, diphoton and $\chi_{c(b)}$ meson at the Tevatron. In leading order (LO) QCD, such exclusive processes can occur through exchange of a color-singlet two gluon system between nucleons, leaving large rapidity gaps in the forward regions. One of the two gluons takes part in a hard interaction while the other serves to neutralize the color. This type of production is generally suppressed by the Sudakov form factor. However, it's potentially a useful channel to search for the light Standard Model Higgs boson (predominantly decaying to $b\bar{b}$) at the LHC, since exclusive $b\bar{b}$ production is expected to be significantly suppressed by a helicity selection ($J_Z = 0$) rule. Our goal of studies is to establish exclusive production experimentally and measure the cross sections of the exclusive processes to calibrate theoretical calculations of exclusive Higgs production at the LHC.

2 Run II Diffraction Measurements

In Run II, CDF has studied various topics on diffraction, including Q^2 dependence of F^D_{jj} in SD and productions of exclusive dijet and exclusive diphoton, for which the results will be discussed below. Two "Miniplug" (MP) calorimeters cover the forward pseudorapidity region $3.6 < |\eta| < 5.2$, and 7 stations of scintillation counters, called Beam Shower Counters (BSC), mounted around the beam pipe, extend the coverage to the very forward region of $5.4 < |\eta| < 7.4$. The Roman Pots (RP) used in Run I were re-installed and are being operated to trigger on leading antiprotons in the kinematic range $0.03 < \xi < 0.1$ and $0 < |t| < 3$ GeV^2, where ξ is the fractional momentum loss of the antiproton and t is the four momentum transfer squared.

3 Diffractive Dijet Production

Triggering on a leading antiproton in the RP in conjunction with at least one jets in calorimeters, diffractive dijet events have been studied. Using a ND dijet sample triggered only on the jet requirement, the ratio R^{SD}_{ND} is measured as a function of x_{Bj}, as shown in Fig. 1 (left). This figure shows the ratios for different Q^2 values obtained from different jet E_T triggers. Here Q^2 is defined as the square of average value of the mean dijet E_T. In the range $100 < Q^2 < 10000$ GeV^2 no significant Q^2 dependence is observed, which indicates QCD evolution of the Pomeron could be similar to that of the proton.

A Q^2 dependence of the t in diffractive dijet events is also examined. Fig. 1 (right) shows the t distributions (with arbitrary normalization) for different Q^2 values spanned over the wide range. The slope at $t = 0$ GeV/c^2 appears to be quite independent of Q^2 and is close to the one in standard diffractive t distribution. Measurement of the slope values is currently under way.

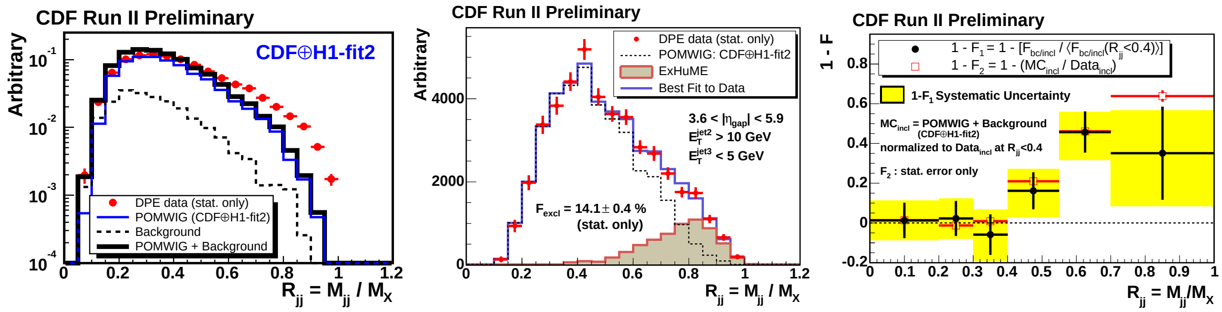

Figure 2: *Left*: R_{jj} of the data (points) and POMWIG MC prediction (thick solid histogram) composed of DPE dijet events (thin solid histogram) and non-DPE background events (dashed histogram). The data and the MC prediction are normalized to a same area. *Center*: best fit (solid histogram) to the data (points) obtained using inclusive (dashed line) and exclusive ExHuME (shaded histogram) MC predictions for the R_{jj} shape. *Right*: One minus the ratio F, obtained from heavy flavor jet ratio (F_1) and inclusive data-POMWIG comparison study (F_2), as a function of R_{jj}. Details of the plot are described in the text.

4 Search for Exclusive Dijet Production

We have implemented in Run II a dedicated trigger that requires a BSC gap on the proton-side in addition to the requirements for the leading antiproton in the RP and at least one calorimeter tower with $E_T > 5$ GeV (RP+GAP+ST5). Requiring offline an additional gap in the MP on the p-side, we have obtained a large amount of double Pomeron exchange (DPE) dijet events. For those events we examine "dijet mass fraction", R_{jj}, defined as the invariant mass M_{jj} of the two highest E_T jets divided by the mass M_X of the whole system (except leading nucleons); $R_{jj} = M_{jj}/M_X$ [b]. This observable should be sensitive to how much the event energy is concentrated in the dijet. The R_{jj} of exclusive dijet events is expected to be peaked around $R_{jj} \sim 0.8$ and have a long tail towards low R_{jj} due to hadronization of partons causing energy leak from jet cones and also the presence of gluon radiations in the initial and final states.

The signal search is performed by comparing the data with predictions for inclusive DPE dijet events in the R_{jj} distribution shape and looking for an excess of events in high R_{jj} region. We use POMWIG Monte Carlo event generator [4] (with detector simulation) to simulate the DPE dijets. Fig. 2 (left) shows a comparison of the R_{jj} shapes between the data and the MC prediction composed of DPE dijet events and non-DPE background events. The data and the MC prediction are normalized to same area. We have examined various Pomeron PDFs and underlying events (Pomeron remnants) in the MC, and find that it is hard to reproduce the data excess at high R_{jj} by any of those changes. Two exclusive dijet production models implemented in ExHuME [5] and DPEMC [6] (Exclusive DPE mode) have also been studied. Fig. 2 (center) shows the best fit to the data R_{jj} shape obtained from the inclusive POMWIG and the exclusive ExHuME predictions for the R_{jj} in events with dijets of $E_T > 10$ GeV and a third jet veto of $E_T^{jet3} < 5$ GeV. The third jet veto is introduced because the exclusive MC generates only a LO $gg \to gg$ process. The fit shows the data excess can be well described by the presence of exclusive dijets. The exclusive DPE model in DPEMC also provides a good agreement with the data in the excess shape.

According to Ref. [3], LO process of exclusive dijet is dominated by $gg \to gg$ and contributions from $gg \to q\bar{q}$ are strongly suppressed by the helicity selection rule. To check this prediction, we search for the suppression of heavy flavor (b and c) jets in exclusive-dominant (high R_{jj}) region. We use a 200 pb^{-1} data sample triggered on the requirements of the RP+GAP+ST5 and at least one displaced vertex track with $p_T > 2$ GeV/c. The displaced track requirement effectively

[b] The system mass M_X is obtained from 4-momenta of all calorimeter (massless) towers and the dijet mass M_{jj} is calculated from the calorimeter tower energies inside the R=0.7 cones of jets.

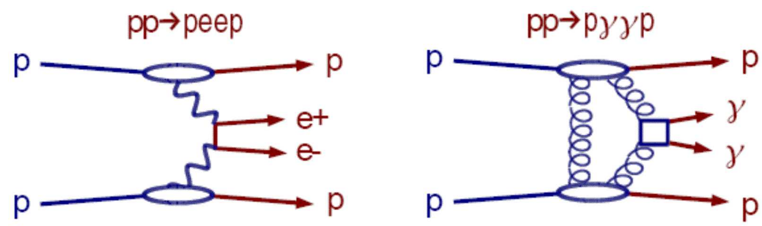

Figure 3: *Left*: Exclusive production of e^+e^- pair through two photon exchange $\gamma\gamma \to e^+e^-$ in $\bar{p}p$ collision. *Right*: Exclusive production of $\gamma\gamma$ pair via gluon-gluon fusion $gg \to \gamma\gamma$ with a quark loop in $\bar{p}p$ collision

enhance heavy flavor contents in the sample. We measure the ratio F of heavy flavor jets to all jets as a function of R_{jj} of the events. The result is presented in Fig. 2 (right) as "$1-F$" versus R_{jj}. The heavy flavor to all jet ratio (F_1 in the figure) is normalized by the weighted average of the F_1 in the range $R_{jj} < 0.4$ so that correlated systematic uncertainties are canceled out. We observe the increasing trend in $1 - F_1$ with increasing R_{jj}, which could be a manifestation of the $J_Z = 0$ selection rule. The result is compared with the inclusive dijet result by showing the "$1 - F_2$", where F_2 is the ratio of the inclusive MC predicted events (normalized to the data at $R_{jj} < 0.4$) to the data. The $1-F_2$ is thus equivalent to the fraction of the observed excess in the data. The $1 - F$ ratios are consistent with each other in both magnitude and R_{jj} dependence.

5 Search for Exclusive Diphoton Production

CDF has also performed search for exclusive diphoton production [7] (Fig. 3) using Run II data. The data used in the search is obtained by a trigger which requires two electromagnetic (EM) towers and BSC gaps in both forward directions. Requiring all the calorimeters to be empty above noise (except for the triggered two EM towers), we have observed 10 events containing two electron candidates with $E_T > 5$ GeV (the two EM towers containing a single track with $p_T > 1$ GeV/c each) and nothing else in the CDF detectors. The observed events appear to be consistent with QED-mediated dielectron production $\bar{p}+p \to \bar{p}+e^+e^-+p$ through two photon exchange $\gamma\gamma \to e^+e^-$. The LPAIR Monte Carlo generator [8] predicts 9 ± 3 events which are consistent with the observed events, though backgrounds in the data are not estimated yet.

In the same dataset the search finds 3 events with two $E_T > 5$ GeV photon candidates (the triggered EM towers associated with no tracks) and nothing else in the detectors. The ExHuME Monte Carlo generator for exclusive diphoton $\bar{p} + p \to \bar{p} + \gamma\gamma + p$ via $gg \to \gamma\gamma$ predicts 1^{+3}_{-1} events. Background estimation is currently under way.

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